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ENERGY CONSUMPTION AND ECONOMIC GROWTH IN BOTSWANA: EMPIRICAL EVIDENCE FROM A DISAGGREGATED DATA ANALYSIS

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Abstract

In this paper we examine the causal relationship between energy consumption and economic growth in Botswana during the period 1980-2016. We disaggregate energy consumption into six components, namely: total energy consumption, electricity consumption, motor gasoline, gas/diesel oil, fuel oil and liquefied petroleum gas. We then compare the results of the disaggregated energy components with that of the aggregated energy consumption level. In order to account for the omission-of-variable bias, we incorporate inflation and trade openness as intermittent variables between the various components of energy consumption and economic growth, thereby creating a system of multivariate equations. Using the ARDL-bound testing approach, the study found a causal flow from economic growth to energy consumption to predominate. This finding has important policy implications as it shows that the buoyant economic growth that Botswana has enjoyed over the years is not energy-dependent, and that the country could pursue the requisite energy conservation policies without necessarily stifling its economic growth. To our knowledge, this study may be the first of its kind to examine in detail the causal relationship between energy consumption and economic growth in Botswana using a multivarite causality model and a disaggregated dataset.

Keywords: Botswana, Disaggregated Energy Consumption, Economic Growth, ARDL-bounds Testing Approach

1. Introduction

The dynamic causal relationship between energy consumption and economic growth has attracted considerable amount of attention in recent years. Theoretically, energy can be regarded as a driver of economic growth because it is one of the key factors of production, along with capital and labour (see Abosedra *et al*, 2015). According to Razzaqi (2011), energy is an essential input for growth and development. Likewise, energy use can also be a limiting factor to economic growth, since other factors of production cannot work properly without it. Studies have also shown that the effect of energy use on economic growth depends largely on the structure of the economy's energy intensity, as well as the stage of that country's economic growth (see Razzaqi 2011: 438). Although early growth models did not explicitly include energy as one of the factors of production, the role of energy in the production process has recently been recognised in the light of the endogenous growth model. Indeed, the increasing role of energy in the production process has led to the incorporation of energy as an input in the production process by many studies. Recent studies have also linked energy to the environmental Kuznets curve theory, developed by Grossman and Krueger (1991). This is because many studies have found that energy plays a crucial role in estimating the turning points of the inverted U-shape relationship between economic growth and environmental quality – popularly known as the environmental Kuznets curve (see Mandal and Chakravarty, 2017). On the empirical front, the relationship between energy consumption and economic growth has been at best inconclusive. While some studies have maintained that there is a unidirectional causality from energy consumption to economic growth, others have argued that it is economic growth that Granger-causes energy consumption. Between these two extremes, there are other studies arguing that there is a bidirectional causal relationship between energy consumption and economic growth. While the majority of the previous studies confirm the existence of a causal relationship between energy consumption and economic growth, there is a fourth view called 'neutrality hypothesis', which argues that there is no causality in either direction between energy consumption and economic growth. Although a number of studies have been conducted on the causal relationship between energy consumption and economic growth in various countries, very few country-based studies have been conducted on African countries. In fact, the majority of the previous studies have mainly concentrated on Asia and the Latin American countries. Studies on sub-Saharan African countries, such as Botswana, are therefore difficult to come by.

It is also worth mentioning that even where such studies have been conducted, the empirical findings are inconclusive in the main. They differ from country to country and over time, as well as the proxy used to measure the level of energy consumption (see Odhiambo, 2009a; 2010). Some of the previous studies have also been found to suffer from a number of methodological weaknesses. For example, some studies used cross-sectional data, which have been found to be unreliable as data lumped together from different countries may not satisfactorily address country-specific issues. The weakness of using the cross-sectional data method has been extensively discussed in the literature (see, for example, Ghirmay, 2004; Quah, 1993; Casselli et al., 1996; Odhiambo, 2008; and Odhiambo, 2010, among others). The other weakness of some of the previous studies hinges on the use of a bivariable causality model, which has been found to suffer from the omission-of-variable bias. Previous studies have found that the introduction of an additional variable in a bivariate setting is likely to change not only the magnitude of the empirical results, but also change the direction of causality between the two studied variables.

The current study, therefore, examines the causal relationship between energy consumption and economic growth in Botswana using disaggregated data for the period 1980-2016. The study aims to answer two critical questions: 1) Is economic growth in Botswana energy-dependent? 2) Which components of energy demand drive economic growth in Botswana? In order to answer these two critical questions, we disaggregate energy consumption into six components, namely: total energy consumption, electricity consumption, motor gasoline, gas/diesel oil, fuel oil and liquefied petroleum gas. We then compare the results of the disaggregated energy components with that of the aggregated energy consumption level. In order to account for the omission-of-variable bias, we incorporate inflation and trade openness as intermittent variables between the various components of energy consumption and economic growth – thereby creating a system of multivariate equations. To our knowledge, this study may be the first of its kind to examine in detail the relationship between energy consumption and economic growth in Botswana using a multivariate ECM-based Granger causality model and a disaggregated dataset.

The rest of the paper is structured as follows: Section 2 gives an overview of energy consumption and economic growth in Botswana. Section 3 deals with the literature review, while section 4 presents the empirical model specification, the estimation techniques and the empirical analysis of the regression results. Section 5 concludes the study.

2. Energy Consumption and Economic Growth in Botswana

Botswana's energy components mainly comprise electricity, wood fuel, liquefied petroleum gas, (LPG), petrol, diesel and aviation gas. Due to the increase in electrification over the years, the use of wood fuel has shown a downward trend in recent years. On the other hand, the use of electricity and liquefied petroleum gas has shown an upward trend. The total electricity consumption, for example, increased from 0.99 Twh in 1990 to 1.90 Twh in 2000, and later to 3.79 Twh in 2004. The consumption of liquefied petroleum gas (LPG), on the other hand, increased from 11 kt in 1990 to 20 kt in 2000, and later to 26 kt in 2014 (see IEA, 2016). Despite the significant increase in electrification, wood fuel still remains the main energy source for cooking, especially in rural households. Botswana's power sector has been dominated by coal, which accounts for about 82% of the country's total power production (see Climate Scope, 2016). Although Botswana has an abundance of energy sources, the country in part relies on energy imported from South Africa and Mozambique. For example, in 2011, it is estimated that about 66% of Botswana's electricity demand was sourced from South Africa, while another 22% was sourced from Mozambique. It is projected that the peak prior demand will increase to 902 MW by 2020 from 578 MW in 2012 (see REEP, 2014). Botswana's electrification rate is very impressive when compared with some African countries. For example, by 2012, about 58% of the country's population had access to grid electricity services. Botswana energy policy has over the years been guided by the country's Vision 2016, Nation Energy policy and Botswana Energy Master Plan. The overall goal of the country's National Energy Policy is to meet the energy needs of Botswana for social and economic development in a sustainable manner (see Government of the Republic of Botswana, National Energy Policy, 2009). According to Vision 2016 plan, the country's energy target was to achieve 80% national power access and 60% rural power access by 2016 (see also REEP, 2014).

On the economic growth front, it is worth noting that Botswana is currently one of the most prosperous countries in Africa. The country grew from being one of the least-developed economies in the 1960s, to one of the middle-income economies in Africa. In fact, Botswana is currently one of the few upper middle-income countries in sub-Saharan Africa (see Odhiambo, 2013). Between 1967-2006, for example, the country's economic growth rate averaged 9% per year. In 2007, Botswana was listed as the third richest country in Africa, according to GDP per capita. The country had a GDP per capita of about US$14,700, and ranked number 74 worldwide. Although in 2009, Botswana experienced its worst recession in almost four decades, due to the global economic recession, its own recession did not last long. In 2010, the country's real GDP growth increased to about 7%. Currently, the country is ranked number 84 worldwide – with a GDP per capita of about USD 14,000

3. Literature review

The causal relationship between energy consumption and economic growth has been examined extensively in a number of countries in recent years, with conflicting results. Three views exist regarding the relationship between energy consumption and economic growth. The first view, which posits that energy consumption Granger-causes economic growth, has been supported by studies like those of Chang *et al*. (2001) for the case of Taiwan; Wolde-Rufael (2004) for Shanghai; Lee (2005) for the case of developing countries; Altinay and Karagol (2005) for Turkey; Chiou-Wei et al. (2008) for Taiwan, Hong Kong, Malaysia and Indonesia; Akinlo (2009) for Nigeria; Odhiambo (2009a) for Tanzania; Odhiambo (2010) for the case of South Africa and Kenya; Chu (2012) for the case of 13 countries; Dergiades et al. (2013) for Greece; Muhammad *et al*. (2013) for Pakistan; Odhiambo (2014) for the case of Uruguay and Brazil; Abosedra et al. (2015) for Lebanon; Iyke (2015) for Nigeria; Tang *et al*. (2016) for Vietnam; Rahman (2017) for the case of Asian populous countries; Saidi et al. (2017) for the case of the European countries; Cai et al. (2018) for the case of Canada, Germany and the US; Le and Quah (2018) for the case of 14 selected countries in the Asia and the Pacific region; Bekun et al. (2019) for South Africa; and more recently Rahman et al. (2020) for the case of China when coal and oil consumption are used as proxies for energy consumption.

The second view, which supports growth-led energy consumption, includes studies like those by Abosedra and Baghestani (1989) for the case of the US; Cheng and Lai (1997) for Taiwan; Cheng (1999) for the case of India; Yang (2000) for Taiwan; Gosh (2002) for India; Shiu and Lam (2004) for China; Hatemi-J and Irandoust (2005) for Sweden; Narayan and Smyth (2005) for Australia; Al-Iriani (2006) for the case of the Gulf Cooperation Council (GCC) countries; Yoo and Kim (2006) for Indonesia; Chen et al. (2007) for the case of India, Malaysia, Philippines and Singapore; Mehrara (2007) for the case of 11 oil-exporting countries; Mozumder and Marathe (2007) for Bangladesh; Ang (2008) for Malaysia; Chiou-Wei et al. (2008) for Philippines and Singapore for the case of nonlinear Granger causality test; Hu and Lin (2008) for Taiwan; Odhiambo (2010) for the case of the DRC; Onuonga (2012) for Kenya; Zhang and Xu(2012) for China; Ocal and Aslan (2013) for Turkey; Odhiambo (2014) for the case of Ghana and Cote d'Ivoire; Rahmad and Velayutharn (2020) for the case of South Asia; and Rahman et al. (2020) for the case of China when gas consumption is used as a proxy for energy consumption.

The third view, which supports a bi-directional causality between energy consumption and economic growth, includes studies such as Glasure and Lee (1997) for the case of South Korea and Singapore; Asafu-Adjaye (2000) for the case of the Philippines and Thailand; Glasure (2002) for Korea; Paul and Bhattacharya (2004) for India; Chiou-Wei et al. (2008) for Malaysia and Indonesia; Odhiambo (2009b) for South Africa; Apergis and Payne (2010) for the case of 20 OECD countries; Chen-Lang et al. (2010) for Taiwan; Belke et al. (2011) for the case of 25 OECD countries; Zhang (2011) for Russia; Apergis and Payne (2012) for the case of 80 countries; Fuinhas and Marques (2012) for the case of Portugal, Italy, Greece, Spain and Turkey; Tugcu et al. (2012) for the case of the G7 countries; Wesseh and Zoumara (2012) for Liberia; Yidirim and Aslan (2012) for the case of 17 OECD countries; Solarin and Shahbaz (2013) for Angola; Adams et al. (2016) for the case of sub-Saharan African countries; Wang et al. (2016) for China; Mirza and Kanwal (2017) for Pakistan; Saidi et al. (2017) for the case of a global panel of 53 countries; Lin and Benjamin (2018) for the case of Mexico, Indonesia, Nigeria and Turkey (MINT) countries; Eren et al. (2019) for the case of India in the long run; and Kahouli (2019) for the case of OECD countries.

The fourth view, which is also known as the neutrality view, however, argues that there is no formidable relationship between energy and economic growth, and that any perceived relationship could be merely mechanical in nature. Although this view has been somewhat unpopular, it is currently gaining traction in the empirical literature. Some studies whose findings have in one way or another supported this view include those of Altinay and Karagol (2004) for Turkey; Akinlo (2008) for Cameroon, Cote D'Ivoire, Nigeria, Kenya and Togo; Chiou-Wei et al. (2008) for South Korea, Thailand and the United States for the case of both linear and non-linear tests; Payne (2009) for the US; Menegaki (2011) for the case of 27 European countries; Ozturk and Acaravci (2011) for most of the 11 Middle East and North Africa (MENA) countries; Chu (2012) for 24 out of 49 countries; Yildirim et al. (2014) for the case of Bangladesh, Egypt, Indonesia, Iran, Korea, Mexico, Pakistan and Philippines; Jebli and Youssef (2015) for 69 countries; Cetin (2016) for the case of E-7 Countries; Tugcu and Tiwari (2016) for BRICS; and more recently Ozcan and Ozturk (2019) for the case of sixteen (16) emerging economies. Tables 1-4 give a summary of earlier empirical findings on the causal relationship between energy and economic growth in both developed and developing countries.

Table 1: Studies that confirm the energy-led growth hypothesis of the causal relationship between energy consumption and economic growth

Authors	Country/region	Methodology	Causal relationship
Cheng (1997)	Brazil, Mexico and Venezuela	Cointegration and Hsiao's version of Granger causality	EC → Y (Brazil)
Chang et al. (2001)	Taiwan	Cointegration and error-correction modelling techniques	EC → Y
Wolde-Rufael (2004)	Shanghai	Granger causality test	EC → Y
Altinay and Karagol (2005)	Turkey	Dolado–Lütkepohl test using the VARs in levels, standard Granger causality test using the detrended data	EC → Y
Lee (2005)	18 Developing countries	Panel Granger causality test	EC → Y
Chiou-Wei et al. (2008)	Taiwan, South Korea, Singapore, Hong Kong, Indonesia, Malaysia, Philippines, Thailand and USA	Linear and Nonlinear Granger causality	EC → Y (Taiwan, Hong Kong, Malaysia and Indonesia)
Akinlo (2009)	Nigeria	VECM, Granger causality test	EC → Y
Odhiambo (2009a)	Tanzania	ARDL, Granger causality test	EC → Y
Odhiambo (2010)	South Africa, Kenya and Congo (DRC)	ARDL, Granger causality test	EC → Y (South Africa and Kenya)
Chu (2012)	49 countries	Panel causality test	EC → Y (13 countries)
Dergiades et al. (2013)	Greece	Linear and Nonlinear Granger causality	EC → Y
Muhammad et al. (2013)	Pakistan	Granger Causality Test	EC → Y
Odhiambo (2014)	Uruguay and Brazil, Ghana, Cote d'Ivoire	ARDL model, ECM-based Granger causality test	EC → Y (Uruguay and Brazil)

Iyke (2015)	Nigeria	VECM, Trivariate Granger causality	EC→ Y
Abosedra et al. (2015)	Lebanon	VECM Granger causality	EC→ Y
Tang et al. (2016)	Vietnam	Multivariate MWALD causality test	EC → Y
Rahman (2017)	Asian populous countries	FMOLS–DOLS	EC → Y
Saidi et al. (2017)	53 countries	VECM, Granger causality test	EC → Y (for the European countries)
Cai et al. (2018)	G7 countries	ARDL, Granger causality	EC → Y (Canada, Germany and the US)
Le and Quah (2018)	14 selected countries in Asia and the Pacific	Panel Granger causality	EC → Y
Bekun et al. (2019)	South Africa	ARDL bounds testing, Granger causality analysis	EC → Y
Rahman et al. (2020)	China	VECM, Granger-causality tests	EC → Y (for coal and oil consumption proxies)

Note: EC→Y means energy consumption causes economic growth

Table 2: Studies that confirm the growth-led energy consumption hypothesis of the causal relationship between energy consumption and economic growth

Authors	Country/region	Methodology	Causal relationship
Abosedra and Baghestani (1989)	United States	Granger causality	Y →EC
Cheng and Lai (1997)	Taiwan	Granger causality test	Y →EC
Cheng (1999)	India	Hsiao's version of the Granger causality method	Y →EC
Yang (2000)	Taiwan	Granger causality test	Y →EC

Ghosh (2002)	India	Granger causality test	Y → EC
Shiu and Lam (2004)	China	ECK, Granger causality	Y → EC
Hatemi-J and Irandoust (2005)	Sweden	Causality Test Based on Bootstrap Simulation Techniques	Y → EC
Narayan and Smyth (2005)	Australia	Multivariate Granger causality test	Y → EC
Al-Iriani (2006)	Six Gulf Cooperation Council (GCC) countries	Panel co-integration, GMM	Y → EC
Yoo and Kim (2006)	Indonesia	VAR, Granger causality	Y → EC
Mehrara (2007)	11 oil exporting countries	Panel Granger causality	Y → EC
Mozumder and Marathe (2007)	Bangladesh	Cointegration test, VECM	Y → EC
Ang (2008)	Malaysia	Granger causality	Y → EC
Chiou-Wei et al. (2008)	Taiwan, South Korea, Singapore, Hong Kong, Indonesia, Malaysia, Philippines, Thailand and USA	Linear and Nonlinear Granger causality	Y → EC (Philippines and Singapore – for the case of nonlinear Granger causality test)
Hu and Lin (2008)	Taiwan	Hansen-Seo threshold cointegration, VECM	Y → EC
Odhiambo (2010)	South Africa, Kenya and Congo (DRC)	ARDL, Granger causality	Y →EC (Congo (DRC)
Onuonga (2012)	Kenya	Error Correction Model, Ganger-causality	Y → EC
Zhang and Xu (2012)	China	Panel Granger causality test	Y → EC
Ocal and Aslan (2013)	Turkey	ARDL, Toda-Yamamoto Causality Tests	Y →EC
Odhiambo (2014)	Uruguay and Brazil, Ghana, Cote d'Ivoire	ARDL model, ECM-based Granger causality test	EC → Y (Ghana and Cote d'Ivoire)

Rahmad and Velayutharn (2020)	South Asia	Panel FMOLS and DOLS estimation techniques, Dumitrescu-Hurling panel causality tests	Y → EC
Rahman et al. (2020)	China	VECM, Granger-causality test	EC → Y (for gas consumption)

Note: Y→EC means economic growth causes energy consumption

Table 3: Studies that confirm the feedback hypothesis of the causal relationship between energy consumption and economic growth

Authors	**Country/region**	**Methodology**	**Causal relationship**
Glasure and Lee (1997)	South Korea and Singapore	Cointegration, error-correction model	EC↔Y
Asafu-Adjaye (2000)	Asian developing countries	Cointegration and error-correction modelling techniques	EC ↔ Y (Thailand and Philippines)
Glasure (2002)	Korea	Causality test	EC↔Y
Paul and Bhattacharya (2004)	India	Engle–Granger cointegration approach, Granger causality test	EC↔Y
Chiou-Wei et al. (2008)	Taiwan, South Korea, Singapore, Hong Kong, Indonesia, Malaysia, Philippines, Thailand and USA	Linear and Nonlinear Granger causality	EC ↔ Y (Malaysia and Indonesia)
Odhiambo (2009b)	South Africa	Granger causality tests	EC ↔ Y
Apergis and Payne (2010)	20 OECD countries	Granger causality	EC ↔ Y
Chen-Lang et al. (2010)	Taiwan	Granger causality	EC↔ Y
Belke et al. (2011)	25 OECD countries	Cointegration and causality tests	EC↔Y
Zhang (2011)	Russia	Time-varying cointegration and causality tests	EC ↔ Y
Apergis and Payne (2012)	80 countries	Pedroni panel cointegration test, panel ECM approach	EC ↔ Y
Fuinhas and Marques (2012)	Portugal, Italy, Greece, Spain and Turkey	ARDL bounds testing approach	EC↔ Y

Tugcu et al. (2012)	G7 countries	ARDL, Hatemi-J causality tests	EC ↔Y
Wesseh and Zoumara (2012)	Liberia	Non-parametric bootstrapped causality test	EC ↔Y
Yildirim and Aslan (2012)	17 OECD countries	Toda Yamamoto causality test, Bootstrap-corrected causality test	EC ↔ Y
Solarin and Shahbaz (2013)	Angola	VECM Granger causality	EC↔ Y
Adams et al. (2016)	Sub-Saharan Africa	GMM panel data analysis, Panel VAR model	EC ↔ Y
Wang et al. (2016)	China	Granger causality	EC ↔ Y
Mirza and Kanwal (2017)	Pakistan	ARDL–VECM	EC ↔ Y
Saidi et al. (2017)	53 countries	VECM, Granger causality test	EC ↔ Y (Global panel)
Lin and Benjamin (2018)	Mexico, Indonesia, Nigeria and Turkey (MINT),	Panel cointegration, Panel vector error correction models	EC ↔ Y (Global panel)
Eren et al. (2019)	India	VECM, Granger causality test	EC ↔ Y
Kahouli (2019)	OECD countries	Pooled OLS–GLS–GMM	Pooled OLS–GLS–GMM

Note: EC↔Y means there is a bidirectional causal relationship between energy consumption and economic growth

Table 4: Studies that confirm the neutrality hypothesis of the causal relationship between energy consumption and economic growth

Authors	**Country/region**	**Methodology**	**Causal relationship**
Altinay and Karagol (2004)	Turkey	Hsiao's Granger-causality	EC ≠ Y
Akinlo (2008)	11 African countries	ARDL, Granger causality	EC ≠ Y (for Cameroon, Cote D'Ivoire, Nigeria, Kenya and Togo)
Chiou-Wei et al. (2008)	Taiwan, South Korea, Singapore, Hong Kong, Indonesia, Malaysia, Philippines, Thailand and USA	Linear and Nonlinear Granger causality	EC ≠ Y (South Korea, Thailand and the United States – for both the linear and nonlinear causality tests)

Payne (2009)	US	Toda-Yamamoto causality test	EC ≠ Y
Menegaki (2011)	27 European countries	One-way random effect model, Panel causality test	EC ≠ Y
Ozturk and Acaravci (2011)	11 MENA countries	ARDL	EC ≠ Y (for most of the MENA countries)
Chu (2012)	49 countries	Panel causality test	EC ≠ Y (24 countries)
Yildirim et al. (2014)	Bangladesh, Egypt, Indonesia, Iran, Korea, Mexico, Turkey, Pakistan and Philippines	Bootstrap autoregressive metric causality test	EC ≠ Y (Bangladesh, Egypt, Indonesia, Iran, Korea, Mexico, Pakistan and Philippines)
Jebli and Youssef (2015)	69 countries	FMOLS, DOLS, VECM	EC ≠Y
Cetin (2016)	E-7 Countries	FMOLS, DOLS, Granger causality	EC ≠Y
Tugcu and Tiwari (2016)	BRICS	Panel bootstrap Granger causality test	EC ≠Y
Ozcan and Ozturk (2019)	17 Emerging market economies	Bootstrap panel causality test	EC ≠ Y (16 emerging market economies)

Note: EC ≠Y means there is no causality

4. Estimation techniques and empirical analysis

The ARDL bounds testing approach to cointegration

In this study, the ARDL bounds testing approach – based on the work by Pesaran and Shin (1999) and Pesaran *et al* (2001) – is used to examine the cointegration between the various proxies of energy consumption, economic growth, and the two intermittent variables. The advantages of using the ARDL bounds testing approach have been well documented in the literature (see also Odhiambo, 2009a). Firstly, the ARDL does not impose the restrictive assumption that all the variables included in the model must be integrated of the same order. In other words, the ARDL approach could still be applied regardless of whether the variables are integrated of order one [I(1)], order zero [I(0)] or fractionally integrated. Secondly, the ARDL technique has been found suitable even if the sample size is small. Thirdly, it has been found that the ARDL technique generally provides unbiased estimates of the long-run model and valid t-statistics even when some of the regressors are endogenous (see also Harris and Sollis, 2003). Following Pesaran *et al* (2001), the ARDL model used in this study can be expressed as follows:

$$\Delta Y/N_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i}\Delta Y/N_{t-i} + \sum_{i=0}^{n} \alpha_{2i}\Delta EC_{t-i} + \sum_{i=0}^{n} \alpha_{3i}\Delta INF_{t-i} + \sum_{i=0}^{n} \alpha_{4i}\Delta TO_{t-i} + \alpha_5 Y/N_{t-1} + \alpha_6 EC_{t-1} + \alpha_7 INF_{t-1} + \alpha_8 TO_{t-1} + \mu_{1t} \quad \ldots (1)$$

$$\Delta EC_t = \beta_0 + \sum_{i=1}^{n} \beta_{1i}\Delta EC_{t-i} + \sum_{i=0}^{n} \beta_{2i}\Delta Y/N_{t-i} + \sum_{i=0}^{n} \beta_{3i}\Delta INF_{t-i} + \sum_{i=0}^{n} \beta_{4i}\Delta TO_{t-i} + \beta_5 EC_{t-1} + \beta_6 Y/N_{t-1} + \beta_7 INF_{t-1} + \beta_8 TO_{t-1} + \mu_{2t} \quad \ldots (2)$$

$$\Delta INF_t = \pi_0 + \sum_{i=1}^{n} \pi_{1i}\Delta INF_{t-i} + \sum_{i=0}^{n} \pi_{2i}\Delta Y/N_{t-i} + \sum_{i=0}^{n} \pi_{3i}\Delta EC_{t-i} + \sum_{i=0}^{n} \pi_{4i}\Delta TO_{t-i} + \pi_5 INF_{t-1} + \pi_6 Y/N_{t-1} + \pi_7 EC_{t-1} + \pi_8 TO_{t-1} + \mu_{3t} \quad \ldots (3)$$

$$\Delta TO_t = \Omega_0 + \sum_{i=1}^{n} \Omega_{1i}\Delta TO_{t-i} + \sum_{i=0}^{n} \Omega_{2i}\Delta Y/N_{t-i} + \sum_{i=0}^{n} \Omega_{3i}\Delta EC_{t-i} + \sum_{i=0}^{n} \Omega_{4i}\Delta INF_{t-i} + \Omega_5 TO_{t-1} + \Omega_6\, Y/N_{t-1} + \Omega_7 EC_{t-1} + \Omega_8 INF_{t-1} + \mu_{4t} \quad \ldots\ldots \quad (4)$$

Where:

Y/N = Economic growth= real GDP per capita (y)
EC = Energy consumption proxies, namely: total energy consumption (Energy); liquefied petroleum gas (LPGas); motor gasoline (Mgasln); gas/diesel oil (G-Diesel); fuel oil (Fuel); and electricity (Elect);
INF = Inflation;
TO = Trade openness;
α_0, β_0, π_0 and Ω_0 = respective constants;
$\alpha_1 - \alpha_4$, $\beta_1 - \beta_4$, $\pi_1 - \pi_4$, and $\Omega_1 - \Omega_4$ = respective short-run coefficients;
$\alpha_5 - \alpha_8$, $\beta_5 - \beta_8$, $\pi_5 - \pi_8$, and $\Omega_5 - \Omega_8$ = respective long-run coefficients;
Δ = difference operator;
n = lag length;
t = time period; and
μ_{it} = white-noise error terms.

All the data used in this study were obtained from the World Development Indicators and International Energy Agency.

Based on Pesaran *et al* (2001), the bounds test for the long-run relationship between the various proxies for energy consumption, economic growth and the two intermittent variables can be conducted by using the joint F-statistic (or Wald statistic) for cointegration analysis. The interpretation of the F-statistics used is based on the two sets of critical values, as recommended by Pesaran and Pesaran (1997) and Pesaran *et al* (2001) for a given significance level. While the first set of critical values assumes that all the variables included in the ARDL model are I(0), the second set assumes that the variables are I(1). For cointegration among the variables to hold, the computed test statistic must exceed the upper critical-bounds value. In other words, the existence of cointegration among the variables will be rejected if the F-statistic falls below the lower bounds value. However, if the computed test statistic falls between the bounds, the cointegration test is regarded as inconclusive (see also Odhiambo, 2009a; 2010).

$$\Delta Y/N_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} \Delta Y/N_{t-i} + \sum_{i=1}^{n} \alpha_{2i} \Delta EC_{t-i} + \sum_{i=1}^{n} \alpha_{3i} \Delta INF_{t-i} + \sum_{i=1}^{n} \alpha_{4i} \Delta TO_{t-i} + \delta_1 ECM_{t-1} + \mu_{1t} \ldots \ldots \ldots (5)$$

$$\Delta EC_t = \beta_0 + \sum_{i=1}^{n} \beta_{1i} \Delta EC_{t-i} + \sum_{i=1}^{n} \beta_{2i} \Delta Y/N_{t-i} + \sum_{i=1}^{n} \beta_{3i} \Delta INF_{t-i} + \sum_{i=1}^{n} \beta_{4i} \Delta TO_{t-i} + \delta_2 ECM_{t-1} + \mu_{2t} \ldots \ldots \ldots (6)$$

$$\Delta INF_t = \pi_0 + \sum_{i=1}^{n} \pi_{1i} \Delta INF_{t-i} + \sum_{i=1}^{n} \pi_{2i} \Delta Y/N_{t-i} + \sum_{i=1}^{n} \pi_{3i} \Delta EC_{t-i} + \sum_{i=1}^{n} \pi_{4i} \Delta TO_{t-i} + \ + \delta_3 ECM_{t-1} + \mu_{3t} \ldots \ldots \ldots (7)$$

$$\Delta TO_t = \Omega_0 + \sum_{i=1}^{n} \Omega_{1i} \Delta TO_{t-i} + \sum_{i=1}^{n} \Omega_{2i} \Delta Y/N_{t-i} + \sum_{i=1}^{n} \Omega_{3i} \Delta EC_{t-i} + \sum_{i=1}^{n} \Omega_{4i} \Delta INF_{t-i} + \delta_4 ECM_{t-1} + \mu_{4t} \ldots \ldots \ldots (8)$$

Where:

Y/N = y (economic growth)

ECM = error-correction term

$\delta_1 - \delta_4$ = respective coefficients for the error-correction terms

μ_{it} = mutually uncorrelated white-noise residuals; and all other variables and characters are as described in equations 1-4.

It is, however, worth noting that even though the error-correction term has been incorporated in each of the four equations, only equations that are cointegrated will be estimated with an error-correction term (see also Odhiambo, 2010; Narayan and Smyth, 2006; Morley, 2006). Based on equations 5-8, the short-run causality will be determined by the F-statistics, while the long-run causality will be determined by the t-statistics on the coefficients of the lagged error-correction terms (see also Odhiambo, 2010; Narayan and Smyth, 2006; Oh and Lee, 2004).

4.3 Empirical analysis

Stationarity test

Although the ARDL-bounds testing approach does not require variables to be integrated of the same order, the test will be void if the variables are integrated of order two or higher. Consequently, it is important to conduct a unit root test to ensure that no variable is integrated of order two or higher. For this purpose, the study uses Augmented Dickey-Fuller (ADF), DF-GLS and Phillips-Perron (PP). The results of the stationarity tests in levels show that the variables used in this study are not conclusively stationary in levels; hence, they had to be differenced accordingly. The results of all the stationarity tests are presented in Table 5.

TABLE 5: **Stationarity Tests of all Variables**

TABLE 6: **Stationarity Tests of all Variables**

Variable	**Augmented Dickey-Fuller (ADF)**		**Dickey-Fuller generalised least squares (DF-GLS)**		**Phillips-Perron (PP)**		**Augmented Dickey-Fuller (ADF)**		**Dickey-Fuller generalised least squares (DF-GLS)**		**Phillips-Perron (PP)**	
	Stationarity of all Variables in Levels						**Stationarity of all Variables in First Difference**					
	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend
y	-0.187	-2.857	1.214	-2.897*	0.117	-2.907	-5.703***	-5.583***	-5.693***	-5.704***	-6.179***	-5.961***
Energy	-1.291	-2.801	-0.652	-2.880	-1.291	-2.837	-7.106***	-6.997***	-7.115***	-7.001***	-7.106***	-7.042***
LPGas	-1.373	-3.655*	-0.787	-1.259	-1.386	-1.169	-4.972***	-5.104***	-5.051***	-5.184***	-4.982***	-5.103***
Mgasln	-0.792	-6.912***	-0.499	-7.074***	-1.510	-7.484	-7.039***	-6.912***	-7.089***	-7.152***	-10.495***	-10.317***
G-Diesel	1.373	-1.800	1.748	-1.538	1.615	-1.749	-5.230***	-4.699***	-5.155***	-5.894***	-5.226***	-5.749***
Fuel	-2.407	-3.934**	-2.503**	-2.562	-3.151**	-3.064	-4.237***	-4.359**	-4.119***	-4.121***	-12.561***	-12.304***
Elect	1.418	-2.688	1.484	-2.340	1.680	-1.462	-4.592***	-4.917***	-4.254***	-4.250***	-3.177**	-3.653**
Inf	-2.485	-3.480*	-1.032	-3.375**	-2.416	-3.573**	-8.783***	-8.637***	-3.875***	-5.496***	-8.705***	-8.554***
TO	-2.016	-1.945	-1.909	-2.373	-1.509	-0.804	-4.015***	-4.138***	-3.170***	-3.476***	-4.015***	-4.148**

*** denote stationarity at 1% significance level
** denote stationarity at 5% significance level
* denote stationarity at 10% significance level

The results reported in Table 5 show that all the variables are now conclusively stationary after first difference. The ADF, the DF-GLS and the Phillips-Perron results reject the null hypothesis of non-stationarity for all the variables used in this study.

4.3.2 Cointegration Test: ARDL-Bounds Testing Approach

The ARDL-bounds testing approach involves two steps. In the first step, the order of lags on the first differenced variables in equations (1)-(4) is obtained from the unrestricted models. In the second step, we apply the bounds F-test in order to establish whether there is a long-run relationship between the various proxies of energy consumption, economic growth, inflation and trade openness in Botswana. These results are reported in Table 6.

TABLE 6: Bounds F-test for Cointegration

Dependent Variable	F-statistic	Cointegration Status	F-statistic	Cointegration Status	F-statistic	Cointegration Status	F-statistic	Cointegration Status	F-statistic	Cointegration Status	F-statistic	Cointegration Status
	Model 1 (Total energy)		**Model 2 (Liquefied petroleum gas)**		**Model 3(Motor gasoline)**		**Model 4 (Gas/diesel oil)**		**Model 5 (Fuel oil)**		**Model 6 (Electricity)**	
y	0.73	Not cointegrated	0.61	Not cointegrated	0.53	Not cointegrated	1.44	Not cointegrated	0.57	Not cointegrated	0.99	Not cointegrated
Energy	2.82	Not cointegrated	0.48	Not cointegrated	3.80*	Cointegrated	4.21*	Cointegrated	4.46**	Cointegrated	6.67***	Cointegrated
Inf	3.96*	Cointegrated	1.49	Not cointegrated	1.53	Not cointegrated	1.82	Not cointegrated	1.69	Not cointegrated	1.83	Not cointegrated
TO	2.05	Not cointegrated	3.99*	Cointegrated	1.39	Not cointegrated	2.79	Not cointegrated	1.37	Not cointegrated	1.29	Not cointegrated
Asymptotic Critical Values												
							1%		5%		10%	
							I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Pesaran et al. (2001), p.300 Table CI(iii) Case III							4.29	5.61	3.23	4.35	2.72	3.77

Note: *, ** and ***denote statistical significance at the 10%, 5% and 1% levels, respectively.

The results reported in Table 6 show that the calculated F-statistic is higher than the critical value in the inflation equation in the case of Model 1, trade openness equation in the case of Model 2, motor gasoline (Mgasln) equation in the case of Model 3, gas/diesel oil (G-Diesel) equation in the case of Model 4, Fuel equation in the case of model 5, and electricity (Elect) equation in the case of Model 6. The results therefore show that there is a long-run relationship among the variables in all six models.

4.3.3 Analysis of the causality test

The results of the cointegration test show that all the variables used in this study are cointegrated. Hence, we can proceed to test for the short-run and long-run causality among the proxies of energy consumption, economic growth, inflation and trade openness. This is done by incorporating the lagged error-correction term into the inflation equation in the case of Model 1, trade openness equation in the case of Model 2, Mgasln equation in the case of Model 3, G-Diesel equation in the case of Model 4, Fuel equation in the case of Model 5, and Elect equation in the case of Model 6. The results of the causality tests are reported in Table 7.

TABLE 7: Granger-causality Test Results

Model 1 ((Total energy)

Dependent Variable	F-statistics [probability]				ECT_{t-1}
	Δy_t	$\Delta Energy_t$	ΔInf_t	ΔTO_t	[t-statistics]
Δy_t	-	4.417** [0.045]	3.315* [0.080]	0.002 [0.967]	-
Δ $Energy_t$	8.377*** [0.008]	-	0.525 [0.475]	3.372* [0.078]	-
Δ Inf_t	3.875* [0.060]	1.956 [0.174]	-	5.963** [0.022]	-0.629*** [-3.225]
Δ TO_t	11.964*** [0.002]	0.21 [0.651]	4.136* [0.052]	-	-

Model 2 ((Liquefied petroleum gas)

Dependent Variable	F-statistics [probability]				ECT_{t-1}
	Δy_t	$\Delta LPGas_t$	ΔInf_t	ΔTO_t	[t-statistics]
Δy_t	-	0.67 [0.421]	4.291** [0.048]	4.291** [0.048]	-
$\Delta LPGas_t$	3.329* [0.080]	-	0.355 [0.557]	4.153* [0.052]	-
ΔInf_t	4.222** [0.050]	0.499 [0.486]	-	3.707* [0.065]	-
ΔTO_t	10.786*** [0.001]	5.047** [0.034]	5.812** [0.024]	-	-0.654*** [-4.500]

Model 3 (Motor gasoline)

Dependent Variable	F-statistics [probability]				ECT_{t-1}
	Δy_t	$\Delta Mgasln_t$	ΔInf_t	ΔTO_t	[t-statistics]
Δy_t	-	0.035 [0.852]	3.653* [0.067]	5.663** [0.025]	-
$\Delta Mgasln_t$	3.379* [0.078]	-	0.769 [0.978]	6.671** [0.016]	-1.190*** [-6.272]
ΔInf_t	3.424* [0.076]	0.112 [0.741]	-	4.875** [0.036]	-
ΔTO_t	8.636*** [0.000]	4.978** [0.035]	3.596* [0.069]	-	-

Model 4 (Gas/diesel oil)

Dependent Variable	F-statistics [probability]				ECT_{t-1}
	Δy_t	$\Delta G\text{-}Diesel_t$	ΔInf_t	ΔTO_t	[t-statistics]
Δy_t	-	3.204* [0.085]	3.268* [0.082]	0.024 [0.879]	-
$\Delta G\text{-}Diesel_t$	10.624*** [0.000]	-	5.197** [0.031]	2.687 [0.114]	-0.156** [-2.153]
ΔInf_t	2.454 [0.129]	5.026** [0.034]	-	0.377 [0.544]	-
ΔTO_t	9.101*** [0.006]	0.078 [0.782]	4.068* [0.054]	-	-

Model 5 (Fuel oil)						Model 6 (Electricity)					
Dependent Variable	**F-statistics [probability]**				***ECT_{t-1}***	**Dependent Variable**	**F-statistics [probability]**				***ECT_{t-1}***
	Δy_t	$\Delta Fuel_t$	ΔInf_t	ΔTO_t	**[t-statistics]**		Δy_t	$\Delta Elect_t$	ΔInf_t	ΔTO_t	**[t-statistics]**
Δy_t	-	0.387 [0.539]	4.389** [0.046]	5.750** [0.024]	-	Δy_t	-	0.544 [0.468]	3.770* [0.063]	0.701 [0.410]	-
$\Delta Fuel_t$	0.366 [0.551]	-	8.161*** [0.001]	0.668 [0.422]	-0.795*** [-5.009]	$\Delta Elect_t$	1.407 [0.247]	-	3.109* [0.090]	5.656** [0.025]	-0.113* [-2.004]
ΔInf_t	3.104* [0.090]	6.036** [0.021]	-	2.302 [0.141]	-	ΔInf_t	5.935** [0.022]	4.412** [0.046]	-	8.186*** [0.008]	-
ΔTO_t	0.688 [0.415]	0.018 [0.895]	0.667 [0.422]	-	-	ΔTO_t	10.573*** [0.002]	1.499 [0.232]	3.001* [0.096]	-	-

* denote statistical significance at 10% levels

** denote statistical significance at 5% levels

*** denote statistical significance at 1% levels

The empirical results reported in Table 7 show that the direction and the magnitude of the causality between energy consumption and economic growth in Botswana is sensitive to the proxy used to measure the level of energy consumption. It also varies over time. When total energy is used as a proxy for energy consumption (model 1), a short-run bidirectional causality is found to exist between energy consumption and economic growth. This finding has been confirmed by the F-statistics in the corresponding economic growth and energy equations, which have been found to be statistically significant. When liquefied petroleum gas is used as a proxy for energy consumption (model 2), a unidirectional causality from economic growth to energy consumption is found to prevail in the short run. This is confirmed by the F-statistic in the energy consumption equation, which is found to be statistically significant. When motor gasoline is used as a proxy (model 3), a unidirectional causality from economic growth to energy consumption is found to prevail both in the short run and in the long run. This is confirmed by the F-statistic and the coefficient of the error-correction term, which were found to be statistically significant. When gas/diesel oil was used a proxy (model 4), a bidirectional causality between energy consumption and economic growth was found in the short run, but a unidirectional causality from economic growth to energy consumption was found to prevail in the long run. However, when fuel and electricity consumption were used as proxies for energy consumption (models 5 and 6), no causality was found to prevail in either direction between energy consumption and economic growth in Botswana. This finding applies irrespective of whether the causality is estimated in the short run or in the long run.

In summary, the study found the causal flow from economic growth to energy consumption to predominate. Other results show that the relationships between inflation and economic growth, inflation and energy consumption, trade openness and economic growth and trade openness and energy consumption also depend on the energy proxy used, as well as the time frame. When total energy consumption was used as a proxy: i) a bidirectional causality between inflation and economic growth was found to prevail in the short run, but a unidirectional causality from economic growth to inflation was found to prevail in the long run; and ii) a unidirectional causality from economic growth to trade openness and from trade openness to energy consumption was found to prevail in the short run. When liquefied petroleum (LP) gas was used as a proxy: i) a bidirectional causality was found to prevail between inflation and economic growth in the short run; ii) a bidirectional causality between trade openness and economic was found in the short run, while a unidirectional causality from economic growth to trade openness was found to prevail in the long run; and iii) a bidirectional causality between trade openness and energy consumption was found in the short run, while a unidirectional causality from energy to trade openness was found to predominate in the long run. When motor gasoline was used a proxy: i) a bidirectional causality between inflation and economic growth, and between trade openness and economic growth was found in the short run; and ii) a unidirectional causality from trade openness to energy consumption was found to prevail in the long run, while a feedback relationship was found to exist in the short run. When gas/diesel oil was used as a proxy: i) a unidirectional causality from inflation to economic growth was found to prevail in the short run; ii) a bidirectional causality between inflation and energy was found in the short run, while a unidirectional causality from inflation to energy was found to prevail in the long run; and iii) a unidirectional causality from economic growth to trade openness was found to predominate in the short run. When fuel oil was used as a proxy: i) a bidirectional causality between inflation and economic growth was found in the short run; ii) a unidirectional causality from inflation to energy consumption was found to dominate in the long run, while a bidirectional causality between inflation and energy was found to exist in the short run; and iii) a unidirectional causality from trade openness to economic growth was found to dominate in the short run. Finally, when electricity was used as proxy: i) a bidirectional causality between inflation and economic growth was found in the short run; ii) a unidirectional causality from inflation to energy was found to predominate in the long run, but a bidirectional causality between inflation and energy was also found to exist in the short run; iii) a unidirectional causality from economic growth to trade openness was found in the short run; and iv) a unidirectional causal flow from trade openness to energy consumption was found to exist both in the short and in the long run.

5. Conclusion and policy implications

This study aims to examine the causal relationship between energy consumption and economic growth in Botswana during the period 1980-2016. The study was motivated by the lack of adequate empirical research on the energy-growth nexus that could appropriately inform policymakers on the relationship between increased energy consumption and economic growth. The study attempts to answer two critical questions: 1) Is economic growth in Botswana energy-dependent? 2) Which components of energy demand drive economic growth in Botswana? In order to answer these questions, the study disaggregated energy consumption into six components, namely: total energy consumption, electricity consumption, motor gasoline, gas/diesel oil, fuel oil and liquefied petroleum gas. In order to account for the omission-of-variable bias, the study used inflation and trade openness as intermittent variables between the various components of energy consumption and economic growth, thereby creating a system of multivariate equations. Using the Autoregressive Distributive Lags (ARDL) Bound testing approach, the study found that the causal relationship between energy consumption and economic growth in Botswana is sensitive to the proxy used to measure the level of energy consumption. When total energy consumption is used a proxy for energy demand, a bidirectional causality is found to be prevalent, but only in the short run. When the gas/diesel oil is used, a bidirectional causal relationship is found to prevail in the short run, but a unidirectional causality from economic growth to energy consumption is found to prevail in the long run. When motor gasoline is used as a proxy, a unidirectional causality from economic growth to energy consumption is found to prevail in both the short and the long run. When LP gas is used as a proxy, a unidirectional causality from economic growth to energy consumption was found to prevail in the short but not in the long run. However, when electricity and fuel were used as proxies, no causal relationship was found to exist between economic growth and energy consumption in either the short or the long run. This further reinforces the neutrality hypothesis that has been found to exist in recent studies. Overall, the study found a causal flow from economic growth to energy consumption to dominate. This finding has important policy implications as it shows that the buoyant economic growth Botswana has enjoyed over the years is not energy-dependent; and that the country could pursue the requisite energy conservation policies without necessarily stifling its economic growth. Moreover, given that Botswana – like many other sub-Saharan African countries – relies on imports of electricity and other petroleum products, the implementation of energy conservation policies will not only enable the country to reduce its energy usage to a sustainable level, but it will also ensure that the country maintains a sufficient supply of energy resources for future use. In addition, it will enable the country to also mitigate the associated negative environmental effects of fossil fuels. Although all efforts have been made to make this study analytically defensible as possible, like many other scientific research studies, it suffers from a few limitations. Since the study used a linear model, it could not examine the asymmetric causal relationship between energy consumption and economic growth in Botswana. So it is recommended that future studies could explore the possibility of using non-linear models so as to test whether the findings from a non-linear model could differ fundamentally from those reported in this paper.

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